ESTIMATES OF GROWTH RATES FOR NORTH PACIFIC ALBACORE,

THUNNUS ALALUNGA (BONNATERRE), BASED ON AN ANALYSIS OF TAG RETURNS[1]

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INTRODUCTION

Growth rates of North Pacific albacore, Thunnus alalunga (Bonnaterre), have been estimated by counting vertebral rings (Uno 1936; Aikawa and Kato 1938; Partlo 1955), examining scale circuli (Nose et al. 1957; Bell 1962; Yabuta and Yukinawa 1963), tracing progressions of length modes (Brock 1943; Suda 1954), and by measuring tagged fish at release and recapture (Otsu 1960; Clemens 1961). Of these techniques, only tagging provides direct estimates of growth rate, and the tagging results of Otsu and Clemens are reasonably consistent with the conclusions of Yabuta and Yukinawa's scale analysis and Suda's modal progression work. However, as Shomura (1966) noted in a review of tuna growth studies, comparisons are complicated by the biases and uncertainties peculiar to each method. For example, in the case of tagging we assume that the growth rate is unaffected by stresses resulting from capture, handling and tagging, and from the burden of carrying the tag itself. Conclusive results will require that the basic assumptions of any particular method be tested and verified.

In this paper, we present new estimates of growth parameters based on recent tag-recapture experiments conducted jointly by the National Marine Fisheries Service (NMFS) and the American Fishermen's Research Foundation (AFRF).[3] We use the standard von Bertalanffy growth model, but also briefly explore some extensions. Sequential estimation of the parameters L_∞ and K allows us to test hypotheses concerning variation in growth rate between tagged fish recaptured in different ocean regions.

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[3]AFRF administers revenues derived from a landing assessment paid by U.S. albacore fishers.

Transpacific recaptures of albacore tagged in the eastern North
Pacific off the U.S. west coast and in the western North Pacific off Japan
have established the interdependence of the United States and Japanese
North Pacific albacore fisheries, and have also fostered the hypothesis of
a single, common stock (Ganssle and Clemens 1953; Clemens 1961; Otsu and
Uchida 1963; Laurs and Lynn MS.[4] However, our results add to growing

[4]Laurs, R. M., and R. J. Lynn. Manuscr. in prep. Seasonal migration
of North Pacific albacore, Thunnus alalunga, into North American coastal
waters: Distribution, relative abundance, and association with Transition
zone waters. Southwest Fisheries Center, La Jolla Laboratory, National
Marine Fisheries Service, NOAA, La Jolla, CA 92038.

evidence that the North Pacific albacore population is not homogeneous,
as usually assumed, but is composed of at least two subgroups with dif-
ferent migration patterns, energy budgets, and growth histories.

METHODS
Tagging Procedures

Albacore were caught in the eastern North Pacific and tagged
aboard U.S. commercial jig and bait fishing vessels on charter to AFRF.
Approximately 70% of the tagging was done by commercial fishermen trained
in tagging procedures, the rest by NMFS technicians. Single Floy[5]

[5]Mention of a commercial company or product does not constitute
an endorsement by the National Marine Fisheries Service, NOAA.

spaghetti-dart tags were inserted on the left side below the second
dorsal fin with the aid of a beveled stainless steel tube, so that the tag
barb was lodged in the pterygiophores of the fin. Only fish judged to be
in very good condition were tagged; fish hooked in the roof of the mouth
or showing signs of extreme exhaustion or severe bleeding were rejected.

For each tagged fish a record was kept on (1) tag number, (2) date and time of release, (3) fork length at time of release, (4) condition at tagging, and (5) longitude and latitude of release. Additional tagging details are given in Laurs et al. (1976).

Recovery Procedures

Recoveries were made by sport and commercial fishers, unloaders, and cannery workers. In most cases information was obtained on (1) tag number, (2) date of recapture, (3) fork length at time of recovery, and (4) longitude and latitude of recapture. Most recapture locations were given as loran coordinates, which we converted to longitude and latitude, but the recapture locations for tags recovered by unloaders and cannery workers were often reported inexactly, e.g., as "off central California." Direct measurements of fork length were available for about half the fish recovered. For most of the remainder only the weight at recovery was given, and fork length was estimated using Clemens' (1961) weight-length relation.

Data Screening

The tag return data were screened to exclude cases where information was incomplete, unreliable, or clearly inaccurate. Out of 443 tag returns made from 1971 through 1976, 201 were rejected Table 1 (Table 1). In 6 cases length at release was not measured, in 88 cases the recapture date was unknown, and in 50 cases neither length nor weight was measured at recovery. In 43 other rejected cases the length at recovery was not measured and the weight only guessed without the

use of scales. Additionally, in 13 instances a gross error was apparent in the measurement of fork length either at release or recovery.

The final accepted data set of 242 cases includes observations on 19 albacore showing negative estimated growth. We assume these are a result solely of measurement error, or error in estimation in cases where the recovery weight was converted to length, and we assume such error occurs throughout the data set independently of size or time out.

One of the common steps in screening tag recovery data for growth studies is to partition the data according to length at release, compute linear regressions of growth increment on time out within each subset, and then reject rare observations, say those departing from expectations by more than two standard deviations (Schaefer et al. 1961; Joseph and Calkins 1969). We abandoned this step because the 14 "outliers" it identified were actually statistically consistent with the three regression models, because the procedure has no sensible stopping rule, and because even with length at release fixed the expected relationship between growth increment and time out is nonlinear.

Grouping of Data

Table 2

The selected data were cross-classified by location of tagging and location of recapture (Table 2). Forty-eight percent of the 242 tagged fish were released inshore (east of 130°W), and of these 67% were released south of 38°N, the remainder north of this latitude. Eighty-one percent of recaptured fish released south of 38°N were recovered in the same area, with 18% recovered either inshore north

of 38°N or west of the 180° line. Of the recovered fish tagged north

of 38°N, only 18% were recaptured inshore south of 38°N, and the rest

were recovered in the northern inshore area or in the eastern hemisphere.

Of the recovered fish tagged and released offshore (west of 130°W),

75% were recaptured either inshore north of 38°N or west of 180°, and

only 24% were recovered in the southern inshore area.

Tag returns were grouped into three categories depending on
recapture location:

1. Group A   includes all fish recaptured inshore south of 38°N,
             except those released inshore north of 38°N.

2. Group B   consists of tag recoveries made inshore north of 38°N,
             excluding those released inshore south of 38°N.

3. Group C   includes all tag recoveries made west of the 180°
             meridian.

The three groups together comprise 227 recaptues; excluded are seven

fish tagged inshore north of 38°N and recovered south of this line,

six fish released south of 38°N and recaptured in the northern inshore

area, and the two tags with no information on recovery location.

Growth Models

We used observations on growth increment, length at tagging

and time at liberty to estimate the growth rate, K, and the asymptotic

length L_∞, of the standard deterministic von Bertalanffy model. In

addition, we considered some extensions of the von Bertalanffy model

which allow the growth rate to vary with age in a simple manner.

In general terms, we assumed that the expected growth increment for the jth fish in the ith group ($i = 1, \ldots, m$; $j = 1, 2, \ldots, n_i$), given the initial length and time out, could be stated as

$$E(\Delta L_{ij}) = \int_{t_{ij}}^{t_{ij} + \Delta_{ij}} G(u) \left(L_\infty - L(u) \right) du$$

where

$$E(\Delta L_{ij}) = \text{expected growth increment of } j^{th} \text{ tagged fish in } i^{th} \text{ group during } (t_{ij}, t_{ij} + \Delta_{ij})$$

$$= L(t_{ij} + \Delta_{ij}) - L(t_{ij})$$

t_{ij} = age of jth fish in i^{th} group at time of release

Δ_{ij} = time at liberty for j^{th} fish in i^{th} group

$L(u)$ = length at age u

L_∞ = asymptotic length

$G(u)$ = unspecified age-dependent growth rate.

If we set $G(u) = K$ = constant, we have the standard von Bertalanffy model, and

$$E(\Delta L_{ij}) = (L_\infty - L_{1_{ij}}) \, [1 - \exp (-K \, \Delta_{ij})]$$

where $L_{1_{ij}} = L(t_{ij})$.

We call this Model 1. (In this model and others that follow, we omit subscripts on parameters, even though group-specific parameters are implied.)

In Model 1 we assume that the ratio of instantaneous growth rate $\frac{dL(u)}{du}$, to potential growth, $L_\infty - L(u)$, is K, a constant. Instead, we may suppose generally that this ratio varies with age. We considered two such situations. In the first, Model 2, we assume that stresses due to capture, handling, and tagging will initially reduce the growth rate of a tagged fish below its usual level, but that as time passes the normal growth process will be restored. Specifically, in our analysis of Model 2 we assume the standard model holds for untagged fish but that when a fish is tagged its normal growth pattern is interrupted, such that

$$G(u) = K, \qquad\qquad\qquad 0 < u < t_{ij}$$
$$G(u) = K\{1 - \alpha \exp[-\beta(u - t_{ij})]\}, \qquad t_{ij} \leq u$$

We assume $K \geq 0$, $\beta > 0$ and $0 \leq \alpha \leq 1$.

Model 2 says that following tagging the growth rate is immediately reduced to a fraction $(1 - \alpha)$ of its normal value, K, and then returns to K asymptotically (Figures 1A, 1B). L_∞ is assumed to be unaffected.

In the second extended model, Model 3, we assume the growth rate is a periodic function of time, with the same pattern of growth repeated within each successive year. In addition, we assume fish are born on the same date each year, so that each fish also follows the same age-specific growth cycles. Specifically, we let

$$G(u) = \alpha_1 \sin[\beta_1(u - \delta)] + \alpha_2 \cos[\beta_2(u - \delta)]$$

where α_1 and α_2 are amplitudes of the component functions, β_1 and β_2 are the respective frequencies and δ is a time lag which fixes the origin of the growth rate curve.

Parameter Estimation

In the standard von Bertalanffy model there are two parameters to be estimated, K and L_∞. The usual approach is to estimate them simultaneously, and we did so using the FORTRAN program BGC4 written by P. K. Tomlinson (Abramson 1971). This routine finds K and L_∞ as those parameter values which minimize

$$S = \sum_{j=1}^{n_i} \{L_{2_{ij}} - [L_\infty - (L_\infty - L_{1_{ij}}) \exp (-K \Delta_{ij})]\}^2$$

where $L_{2_{ij}} = L(t_{ij} + \Delta_{ij})$.

Since $E(L_{2_{ij}})$ is a nonlinear function of K, parameter estimates derived using this procedure are prone to serious bias unless observations on $L_{2_{ij}}$ are made over a wide range of $L_{1_{ij}}$ and Δ_{ij}. Presumably, it is also desirable that they be made uniformly in the plane of these two variables.

The parameters of Models 2 and 3 may also be estimated jointly using nonlinear least squares methods, but estimates of L_∞ and correlated parameters suffer the same drawbacks as estimates of the standard von Bertalanffy model parameters derived from BGC4.

An alternative approach in fitting all three models is to estimate L_∞ and the other parameters sequentially. Where the oldest members of the population have been intensively sampled, a reasonable estimate of L_∞ (at least a lower bound) is the length of the largest fish seen in the catches. With this value of L_∞ determined, the other parameters may be estimated by the least squares method using the general model

$$y_{ij} = -\ln \left(\frac{L_\infty - L_{2_{ij}}}{L_\infty - L_{1_{ij}}}\right) = \int_{t_{ij}}^{t_{ij} + \Delta_{ij}} G(u)\, du + \varepsilon_{ij}$$

where we assume the ε_{ij} are independent errors with zero means and variances σ^2.

This approach handily accommodates any well-behaved form of $G(u)$. In the case of Model 1, the problem of estimating K reduces to a simple linear regression

$$y_{ij} = K\, \Delta_{ij} + \varepsilon_{ij} \tag{1}$$

When reasonably accurate estimate of L_∞ can be made by sampling the catches, this sequential estimation procedure for Model 1 has the advantage that the range of observations on $L_{1_{ij}}$ and Δ_{ij} is not so critical.

With Model 2, the sequential method may be applied to estimate K, α, and β using the equation

$$y_{ij} = K\, \Delta_{ij} - \left(\frac{K\alpha}{\beta}\right)[1 - \exp(-\beta\, \Delta_{ij})] + \varepsilon_{ij} \tag{2}$$

The desirability of fitting this nonlinear model to any particular set of data may be judged by examining the residuals around the least squares fit of Model 1 (equation 1). As is evident Fig. 2 from Figure 2, the detection of nonlinearity in this manner requires that observations be available uniformly over a broad range of Δ_{ij}.

Model 3 parameters α_1, α_2, β_1, β_2, and δ may be estimated sequentially using

$$y_{ij} = (\frac{\alpha_2}{\beta_2}) \{\sin[\beta_2 (t_{2_{ij}} - \delta)] - \sin[\beta_2 (t_{1_{ij}} - \delta)]\} \qquad (3)$$

$$-(\frac{\alpha_1}{\beta_1}) \{\cos[-\beta_2 (t_{2_{ij}} - \delta)] - \cos[\beta_1 (t_{1_{ij}} - \delta)]\} + \varepsilon_{ij}$$

where $t_{1_{ij}} = t_{ij}$ and $t_{2_{ij}} = t_{ij} + \Delta_{ij}$.

Effective use of this model requires that most of the observed values of Δ_{ij} be no larger than about one-quarter of either wavelength, i.e., no larger than $\frac{\pi}{2\beta_1}$ or $\frac{\pi}{2\beta_2}$.

Covariance Analysis

One of our chief objectives was to determine whether growth rates differed between groups of fish, based on estimates of parameters of the standard von Bertalanffy model. Since BGC4 estimates of K and L_∞ are highly correlated, particularly when few large fish are in the sample, and since probability statements concerning intergroup comparisons of both K and L_∞ were not possible, we used the sequential estimation procedure. For the ith group of fish we assumed

$$E(y_{ij}) = K_i \Delta_{ij} \qquad (4)$$

where $y_{ij} = -\ln(\frac{L_\infty - L_{2_{ij}}}{L_\infty - L_{1_{ij}}})$.

We set L_∞ = 125 cm for each group. Then we developed and applied a

zero-intercept covariance analysis to test hypotheses of the form

$$H: K_1 = K_2 = \ldots = K_m = K$$

on the basis of F statistics.

RESULTS

Standard Model

Joint BGC4 estimates of K and L_∞ for Groups A, B, and C are

Table 3   shown in Table 3. We consider the estimates inaccurate, owing to

sampling biases discussed earlier. In particular, we think the

unexpectedly low L_∞ estimates (and correspondingly high K estimates)

are due to the absence of very large albacore in the release and

recovery samples. Of the 227 selected tag returns, 75 exceeded 80 cm

in fork length at recapture, but only 18 were greater than 85 cm

and just 3 were over 90 cm. The average fork length of tagged

albacore at time of release was 63.5 cm (range from 48 to 89 cm),

and at recovery, 75.7 cm (range from 51 to 96 cm).

Because of the difficulties with BGC4 estimates, we based

intergroup comparisons on estimates of K from the sequential estima-

tion procedure. A preliminary F-test showed no significant difference

in $\hat{K}$ between those fish whose lengths at recovery were measured and

those whose lengths were estimated from the weight-length relationship.

Further sequential analyses (as well as the earlier BGC4 estimates)

were therefore based on all data, regardless of how recovery length

was determined.

L_∞ was fixed at 125 cm. (This value is reasonable. Otsu and Sumida (1970) reported an albacore measuring 132.7 cm from the Hawaiian longline fishery, which harvests the very largest albacore known, but specimens over 125 cm are extremely rare.) Group A had the highest growth rate estimate, $\hat{K}_A = 0.210$ (Table 3). Group B had $\hat{K}_B = 0.191$, and Group C had the lowest growth rate estimate, $\hat{K}_C = 0.178$. When Groups B and C were pooled into a "North" category, the resulting $\hat{K}_N$ was 0.184. The estimate of K for all three groups combined was 0.192.

Table 3 also shows the statistics on average time between release and recapture. Group A fish were at liberty an average of 1.0 yr, while Group B fish were out 1.1 yr, and Group C fish, 1.5 yr. Tagged fish from Groups B and C combined were at large an average of 1.3 yr.

The estimates suggest that the "North" fish, Groups B and C, had a lower growth rate than the "South" fish of Group A. Such a difference might arise if, as we suppose, the "North" fish budget more of their available energy for migration compared with the "South" fish, and less for growth. The hypothesis of equal growth rates was tested using the zero-intercept analysis of covariance, and was rejected at the 5% significance level (Table 4, Figure 3). In pairwise comparisons between individual groups, the only significant difference in growth rate was between Groups A and C (Figure 4).

Table 4

Fig. 3

Fig. 4

Are the observed differences in growth rates of tagged albacore consistent with other information? To check this, we examined the length composition of albacore catches along the U.S. west coast (Figure 5). The length-frequency plot for catches north of 38°N during the period when most recaptures were made, 1972-75, showed modes at about 64 and 76 cm, and a hint of one at 54 cm. Catches south of 38°N showed the 54-cm mode, but had primary modes at about 67 and at 80 cm. The discrepancy between modes of the older albacore is further evidence of a slower growth rate for "North" fish, assuming these modes represent fish of the same age. To see if the length-frequency data and tag data agreed, we compared the ratio of $\hat{K}_B$ to $\hat{K}_A$, computed from the tag data, with the expected ratio of these parameters as a function of the difference in length at age, derived from the von Bertalanffy model, viz

Fig. 5

$$\left(\frac{K_B}{K_A}\right)_{LF} = \frac{\ln\left(1 - \frac{L_B}{L_\infty}\right)}{\ln\left(1 - \frac{L_A}{L_\infty}\right)}$$

where L_B = length mode of older "North" inshore fish

L_A = length mode of older "South" inshore fish

Putting L_∞ = 125 cm and substituting L_B = 76 cm and L_A = 80 cm, we calculate that

$$\left(\frac{\hat{K}_B}{K_A}\right)_{LF} = 0.92$$

and with L_B = 64 cm, L_A = 67 cm, and L_∞ = 125 cm, we have

$$\left(\frac{\hat{K}_B}{\hat{K}_A} \right)_{LF} = 0.93.$$

Now, taking the ratio of growth rate estimates derived from tag data we have

$$\left(\frac{\hat{K}_B}{\hat{K}_A} \right)_T = 0.91.$$

These results are strikingly similar and lend credibility to the covariance analysis.

An alternative way to judge the covariance results is to compute the expected fork length under each $\hat{K}$ at annual time steps and compare these with the observed modes of the length-frequency distributions. Starting with some initial fork length, L_1, we used the equation $L_i = a + b\ L_{i-1}$, $i = 2, 3, \ldots$, where $a = L_\infty\ (1 - EXP(-K))$ and $b = EXP(-K)$. Setting L_1 = 54 cm and L_∞ = 125 cm, we found the sequence of lengths 54.0, 66.3, and 76.5 cm for the Group B albacore, and 54.0, 67.4, and 78.3 cm for Group A fish. These are reasonably consistent with the observed sequences of length modes.

Extended Models

Plots of residuals from the standard model against days out did not suggest any particular pattern of systematic deviation from linearity. However, we thought that some of the variability could be attributed to "lack of fit" (Draper and Smith 1966), and examined the

two extended von Bertalanffy models. We fit Model 2 using the sequential estimation procedure (Equation 2) with $L_\infty = 125$ cm. In all cases the least squares estimates of α were on a boundary (0 or 1) and estimates of β were very large. Estimates of K were usually less than 4% larger (in Group A, 12.6% larger) than the corresponding estimates of K from the standard linear model. No significant reduction in residual mean squared error was achieved. Any impact of tagging on growth, of the sort hypothesized in Model 2, is probably masked by the extremely high variability in the data.

We also briefly considered Model 3. We fixed $L_\infty = 125$ cm and fitted the integrated form at Equation 3 to each group of data. The residual mean squared error from the periodic growth model was not significantly less than for Model 1 in any case. This result was not entirely unexpected; since the average time out was greater than 1 yr in each group, detection of seasonal variation in growth rate was effectively ruled out. On the other hand, any strong cycles with a period of about 4 yr or more should have been revealed, if present. Apparently most of the variability in y_{ij} is due either to random measurement errors, or to fluctuations arising from a simple stochastic growth process with expectation given by Equation 4.

DISCUSSIONS AND CONCLUSIONS

Our confidence in the growth analysis results is strengthened
by their consistency with other findings, but the assumptions of our
analysis need to be tested. In particular, we assumed that our estimate
of L_∞, 125 cm, was the same for all groups of North Pacific albacore.
If the "South" fish, Group A, actually tend toward a larger asymptote
in fork length than the "North" fish of Groups B and C then the dif-
ference between estimates of K might not be significant. The value of
L_∞ is not too important; the same conclusions were obtained when we
set L_∞ equal to 120, 130, and 135. But the assumption of equality of
the L_∞ estimates is important, and testing it will be extremely
difficult.

We also assumed that the growth rate was unaltered by the
presence of the tag or by the stress imposed in its application. In
our analysis of Model 2 we explored the question of whether tagging
might have affected growth rate in a specified way, and Model 2 did
not fit our data any better than the standard von Bertalanffy model,
Model 1. Any effect of the sort we hypothesized might easily have
been masked by high variance in the data. Nevertheless, if the effect
of tagging were simply to reduce the normal growth rate, K, suddenly
and permanently to a lower level, K', it would go undetected by our
analysis. To determine the validity of the tag-effect assumption we
need to compare the growth rates of tagged fish with those of untagged,
"control" fish. One promising approach is to combine tagging with recently
developed procedures of otolith analysis (Pannella 1971; Brothers et

al. 1976; Struhsaker and Uchiyama 1976; Uchiyama and Struhsaker MS[6]).

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[6]Uchiyama, J. H., and P. Struhsaker. Manuscr. in prep. Age and growth of skipjack tuna, <u>Katsuwonus pelamis</u>, and yellowfin tuna, <u>Thunnus albacares</u>, as indicated by daily growth increments of sagittae. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

If the otoliths of tagged fish are marked with tetracycline or some other osteophylic agent at the time of release, the information on time of liberty for recaptured fish can be used to determine the rate of ring formation (Inter-American Tropical Tuna Commission 1976). The usual assumption of daily ring deposition may then be tested. Further, the calibrated otolith method may then be used as the principal means of absolute age and growth determination, and may also be used to test assumptions of the tag-recapture method and other procedures. Planning of such experiments for North Pacific albacore is now underway.

We found that the growth rate of North Pacific albacore recaptured either north of 38°N in the U.S. fishery or in the western North Pacific off Japan was significantly lower than for tagged albacore recaptured in the U.S. fishery south of 38°N during 1972-75. The differences in growth rate of tagged fish are remarkably consistent with differences in length-frequency distributions of albacore caught off the United States north of south of 38°N during the period when most recaptures were made. These findings add to a growing body of evidence (Brock 1943; Laurs et al. 1975[7]; Laurs and Lynn 1976[8]; Laurs and Lynn MS[4]) that North Pacific albacore are not as homogeneous as

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[7]Laurs, R. M., R. J. Lynn, and R. N. Nishimoto. 1975. Report of joint National Marine Fisheries Service-American Fishermen's Research Foundation albacore studies conducted during 1975. SWFC Admin. Rep. LJ-75-84, 49 p. Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service, NOAA, La Jolla, CA 92038.

[8]Laurs, R. M., and R. J. Lynn. 1976. Report of joint National Marine Fisheries Service-American Fishermen's Research Foundation albacore studies conducted during 1976. SWFC Admin. Rep. LJ-76-36, 51 p. Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service, NOAA, La Jolla, CA 92038.

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usually assumed, and that there may be at least two subgroups of albacore: one which supported the Japanese pole-and-line fishery and the U.S. fishery in waters north of about 38°N from 1972 to 1975, and another which did not contribute significantly to the Japanese surface fishery, but supported the U.S. coastal fishery south of 38°N during this period. If such a distinction is valid, the situation is surely more complex and dynamic than we have supposed, with each stock's contribution to each fishery varying from year to year. Presumably such variation would be tied directly to changes in oceanographic conditions. And undoubtedly the latitudinal boundary was not fixed exactly at 38°N during 1971-76, as we assumed. If an accurate assignment of tagged fish to "stock" were possible a more powerful test of growth differences could be made.

A finding that more than one subpopulation or stock is involved in the North Pacific albacore fisheries would have very important consequences, of course, both for stock assessment, fishery evaluation and management policy analysis, and for development of accurate catch forecasting systems. It is important that further work be done to identify stocks, and to elucidate their origins, migratory habits, and degree of interchange.

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Table 1.—Number of tagged North Pacific albacore released, returned, rejected, and accepted for growth analysis.

Year	No. tagged fish released	No. tagged fish returned	Rejected tag returns					Total tag returns rejected	No. tag returns accepted for analysis
			Missing release size	Missing recapture date	Missing recovery size	Weight at recovery estimated	Gross measurement error		
1971	887	33	1	7	5	2	0	[1]16	17
1972	1,556	126	1	31	14	11	6	63	63
1973	1,806	107	1	26	8	8	1	44	63
1974	2,490	130	2	20	16	15	5	58	72
1975	1,351	41	0	4	6	7	1	18	23
1976	1,526	6	1	0	1	0	0	2	4
Total	9,616	443	6	88	50	43	13	201	242

[1]One return rejected because tag number was unknown.

Table 2.--Classification of selected tag data
by locations of release and recapture.

| Recapture | East of 130°W | | | West of 130°W | Grand total |
	South of 38°N	North of 38°N	Total		
Eastern Pacific	69	23	92	87	179
South of 38°N	63	7	70	30	100
North of 38°N	6	16	22	57	79
Western Pacific	8	15	23	38	61
Unknown	1	0	1	1	2
Grand total	78	38	116	126	242

Table 3.—Estimates of von Bertalanffy growth parameters for North Pacific albacore by recapture location and estimation method.

Recapture group	Sample size n	BGC4 estimates		Sequential estimates		Average time out $\bar{\Delta}$ (yr)
		$\hat{L}_\infty$ (cm)	$\hat{K}$ (yr^{-1})	Fixed L_∞ (cm)	$\hat{K}$ (yr^{-1})	
A	93	94.5	0.505	125.0	0.210	1.02
B	73	107.5	0.272	125.0	0.191	1.11
C	61	98.5	0.345	125.0	0.178	1.50
B + C	134	102.1	0.310	125.0	0.184	1.29
A + B + C	227	100.9	0.342	125.0	0.192	1.18

Table 4.--Analysis of covariance comparing growth rate of group A with growth rate of group (B + C). Asterisk indicates growth rates are different at 5% significance level.

Source of variation	d.f.	Residual SS	MS	F
Individual lines				
A	92	1.0310		
B + C	133	1.3351		
Pooled	225	2.3661	0.0105	
Common line	226	2.4267		
Difference	1	0.0606	0.0606	5.76**
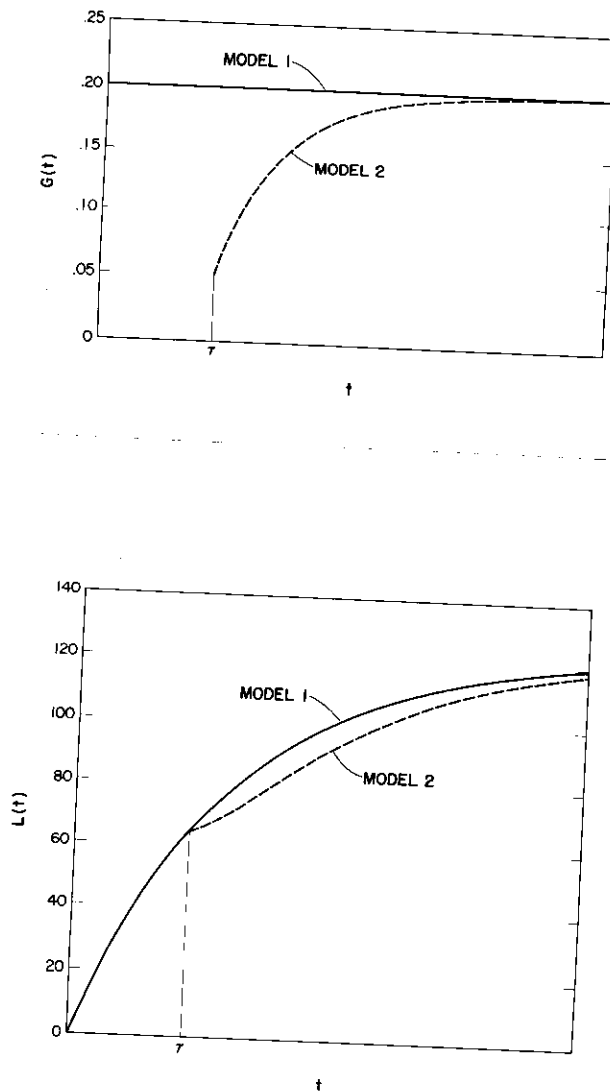
Figure 1.—Standard von Bertalanffy growth model (Model 1), and an extension (Model 2) incorporating a temporary reduction in growth rate, G(t), following tagging at time τ. The resulting growth pattern, L(t) is altered.
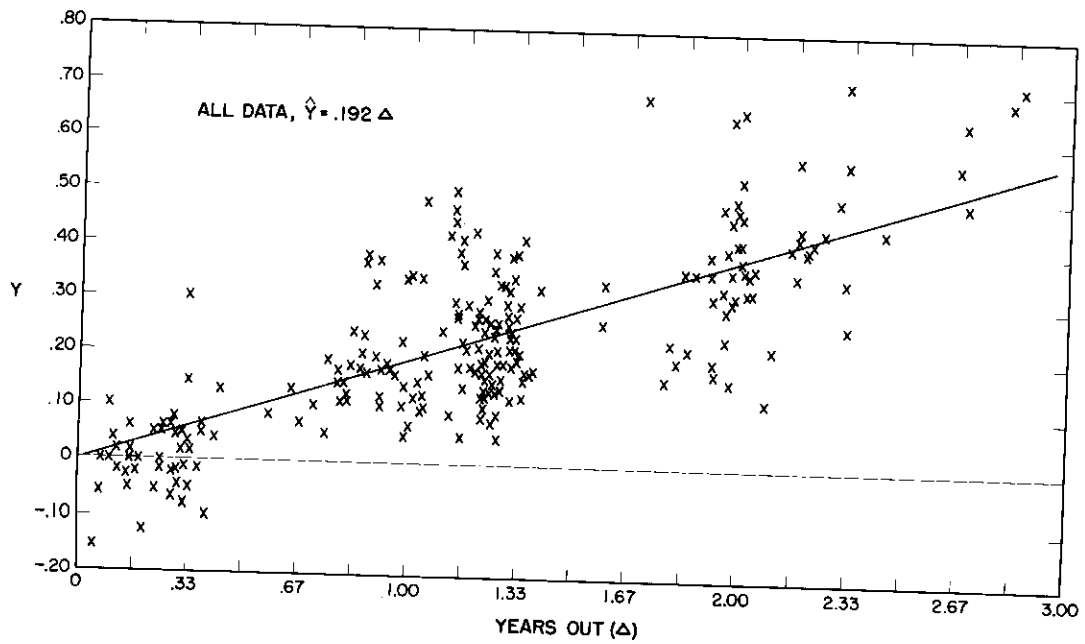
Figure 2.--Regression of growth variable, Y, on years between release and recapture for 227 North Pacific albacore of Groups A, B, and C combined.
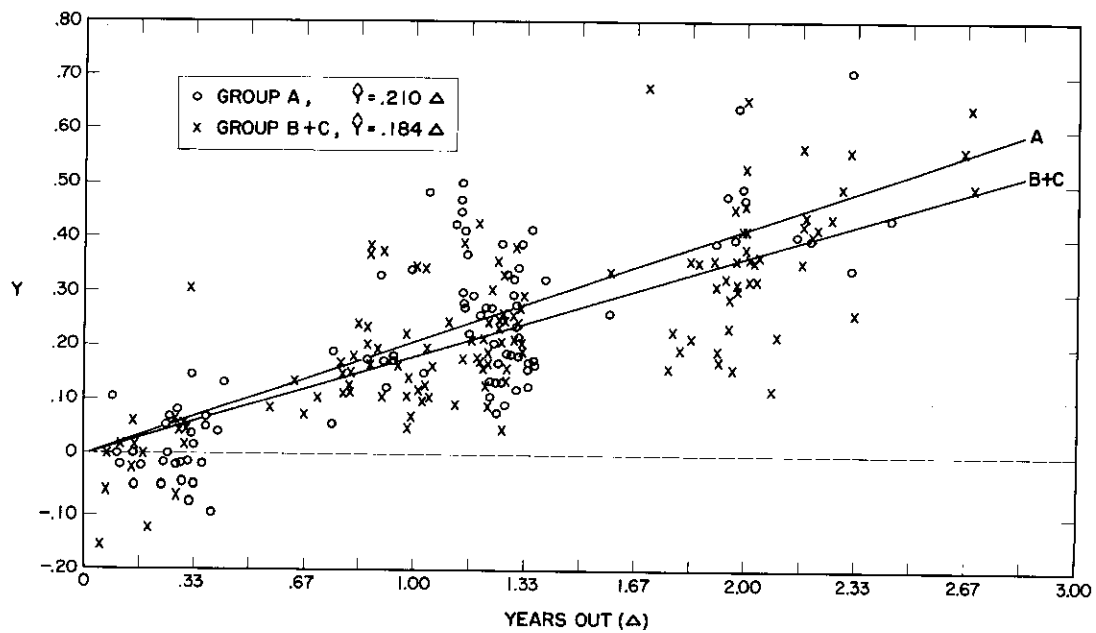
Figure 3.—Regression of growth variable, Y, on years between release and recapture for albacore of Groups A (93 fish) and B + C (134 fish). The slopes are estimates of the von Bertalanffy growth parameter, K, and they are significantly different.
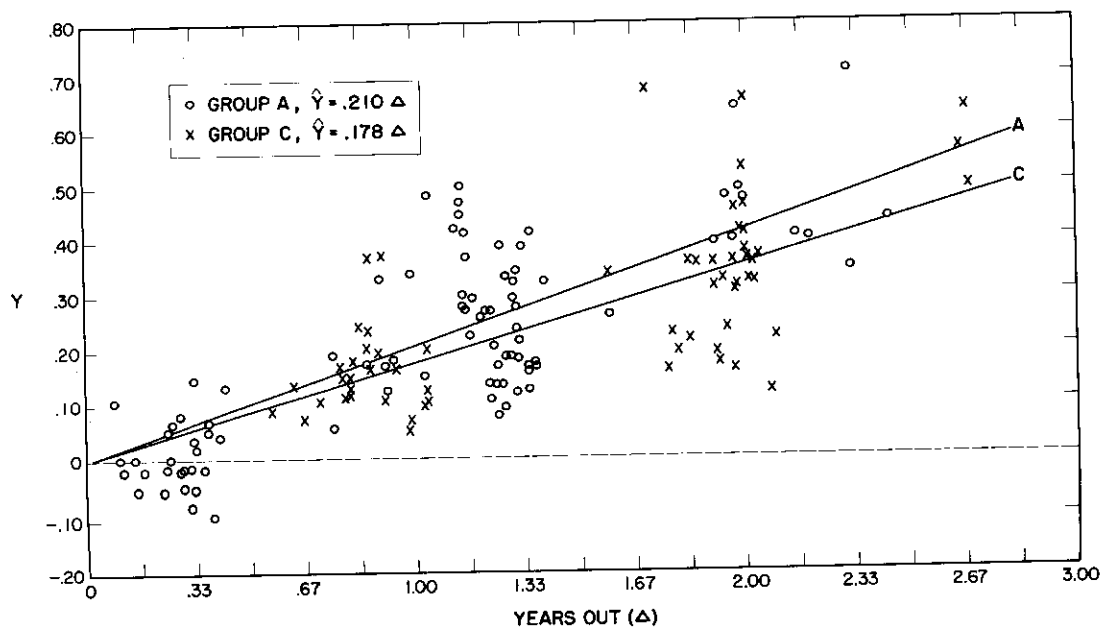
Figure 4.--Regression of growth variable, Y, on years between release
and recapture for albacore of Groups A (93 fish) and C (61 fish).
The slopes are estimates of the von Bertalanffy growth parameter, K,
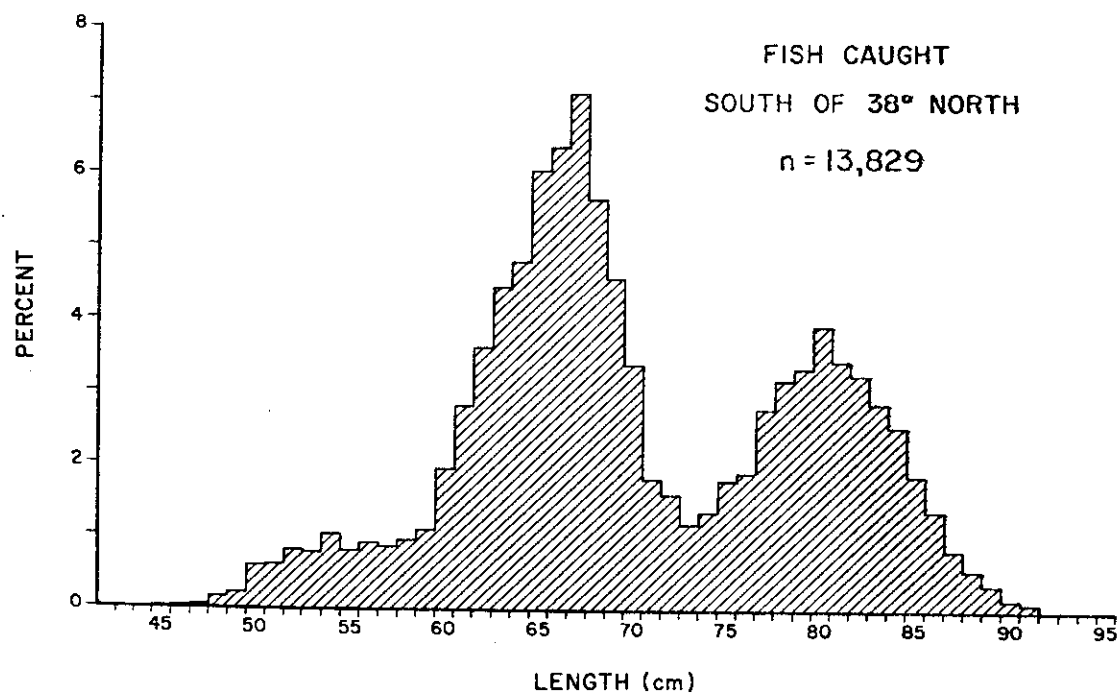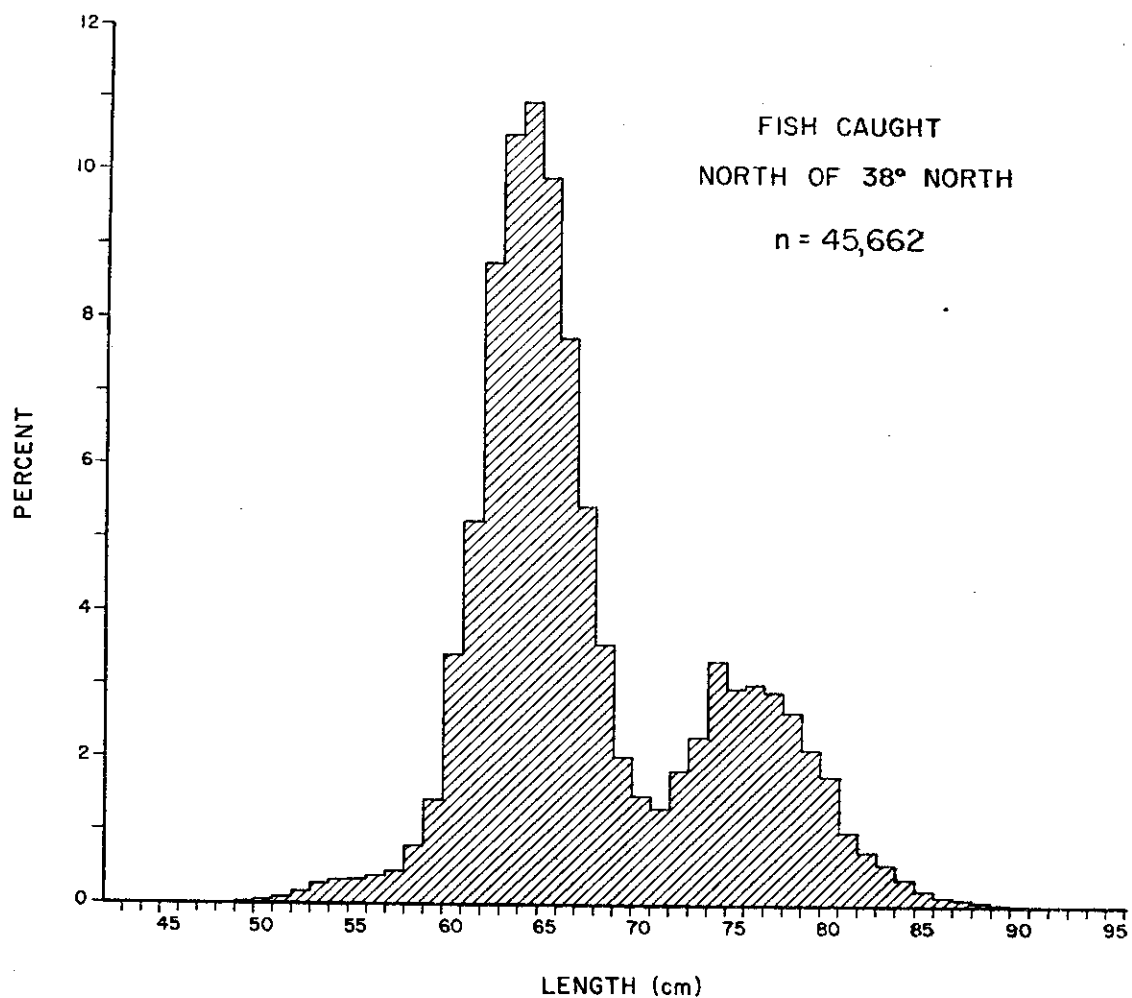and they are significantly different.

Figure 5.—Composite length-frequency distributions for North Pacific albacore caught north of 38°N and south of 38°N off the U.S. west coast during the 1972-75 fishing seasons.